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Evaluation des performances des communications optiques LED-à-caméra

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Les communications LED-à-caméra ont des usages applicatifs très différents en terme de qualité de services. Cependant, les outils d'évaluation de performances utilisés classiquement pour les réseaux radio ne sont ni utilisables, ni facilement adaptables à ce contexte. Aucun modèle analytique ou de simulation n'existe pour les communications LED-à-caméra, qui ne sont évaluées dans la littérature que par des expérimentations, parfois longues et fastidieuses. Ce travail propose un modèle de canal optique entre LED et caméra, basé sur un processus de Bernoulli modulé par une chaîne de Markov et validé par des expérimentations. Ce modèle est intégré ensuite dans le simulateur *CamComSim*, le premier simulateur pour des communications LED-à-caméra.

Mots-clefs : communications optiques, VLC, simulation

1 Introduction

Visible-light communication (VLC) is an enabling technology that exploits illumination to provide a short-range wireless communication link, by modulating the output intensity of a light-emitting diode (LED). Any electronic device which can detect the presence or absence of visible light can be utilized as a VLC receiver, including smartphone cameras, which can be used to detect high-frequency light patterns [1]. LED-to-camera communications exploit the Rolling Shutter readout mode of the smartphone camera [2], where each row of pixels in the picture is exposed in a row-sequential way with fixed time delay. Due to this mechanism, there is a significant time difference between the beginning of the exposure of the first and the last row, making them no longer simultaneous. When an LED is modulated at a frequency higher than the rolling shutter speed, stripes of different light intensity are captured in the image. A row of pixels appears illuminated when the LED was ON during the row exposure time. On the other hand, a row appears dark when the LED was OFF during the exposure time. The intensity and width of the strip depend on the transmitter modulation frequency, allowing us to encode information in these illuminated and dark bands, similarly to the use of a bar code.

LED-to-camera communication opens the door to a wide range of use cases and applications : line-of-sight (LOS) [3] and non-line-of-sight (NLOS) [4] communications have been demonstrated in these settings, as well as ultra-reliable localization solutions [5], sensing [6], or even scene protection against intrusive photographs [7]. However, while analytical models and simulation tools exist for all the major radio technologies, the only way of currently evaluating the performance of a network mechanism over LED-to-camera is to implement and test it. This results in heavy measurement and parameterisation campaigns that need to be repeated anytime a new VLC protocol or feature is imagined. Having access to standard performance evaluation tools in this type of network would certainly accelerate studies in the field, and nicely complement experimental field tests. The work described in this paper aims to fill this gap by proposing models and tools that help in the assessment of LED-to-camera communication network mechanisms.

2 Modeling LED-to-camera communication

In a LED-to-camera system, data is received as a series of dark and illuminated stripes in a picture frame captured by the camera. In the following, we note by f_i the i-th frame captured by the camera and by δ_f the time between the beginning of two consecutive frames. Obviously, even at the highest frame rate allowed by the camera, data is not continuously received, as a minimum time δ_g exists between two frames. This is denoted as the inter-frame gap (IFG). Moreover, as depicted in Fig. 1, the distance between the LED and the camera also has an impact : when the camera is farther away, the LED transmission is captured for a shorter time, resulting in a smaller region of interest (ROI) that embeds information on the picture.

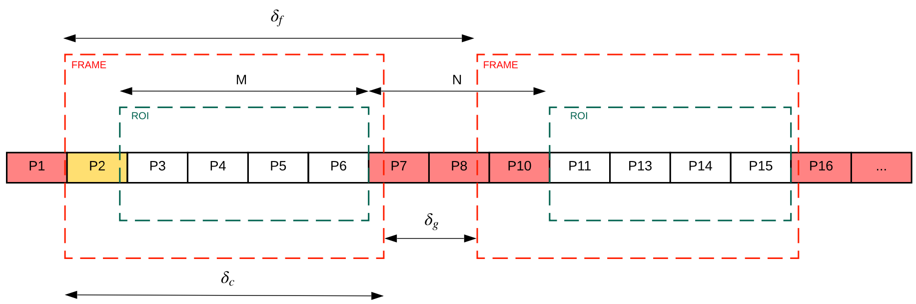

FIGURE 1: Frame capture time and inter-frame interval, and their relation with the MMBP parameters.

We model the LED-to-camera channel using a Markov-modulated Bernoulli process (MMBP), represented in Fig. 2. In this figure, we depict a Markov chain with a total number of $M+N$ states. Each of these states represents a reception time slot, i.e. the time duration needed in order to receive one physical layer message (denoted as PHY-SDU in the following). The transition between two states representing successive time slots is automatic, i.e. it happens with a probability of 1.

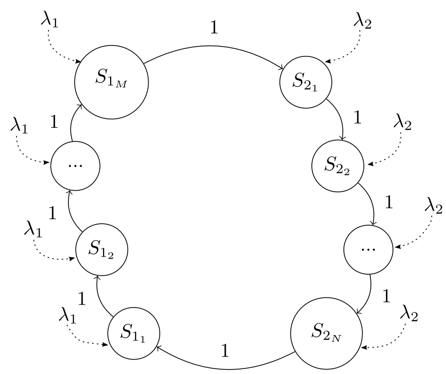

FIGURE 2: The MMBP model of the LED-to-camera channel.

Practically, the $M+N$ states in Fig. 2 represent a δ_f time interval, and they are divided in two groups : M states corresponding to the camera capture time δ_c (S_{ON} states), and N states corresponding to the inter-frame time δ_g (S_{OFF} states). A Bernoulli arrival process is associated with each of these $M+N$ states, representing the reception of a packet.

In S_{ON} states, the camera is receiving packets, and the arrival rate is $\lambda_1 = (1-p_e)$, where p_e is the packet decoding error probability. In S_{OFF} states, the camera is not capturing any pictures, therefore we consider the arrival rate $\lambda_2 = 0$.

We denote as s a state in the Markov chain and we define state $s+j$ as the state reached after j transitions, starting from state s. The probability of being in state s under the steady-state regime can be easily computed as $\pi_s = \frac{1}{N+M}$. At the same time, the probability of noticing no arrivals (i.e. no packet reception) in state s is $p_0(s)$. This can be written as :

$$p_0(s) = \begin{cases} 1, & if \quad s \in N \\ p_e, & if \quad s \in M \end{cases} \tag{1}$$

As it can be seen from the model, the relatively high packet loss probability (compared with RF technologies) is an intrinsic property of the LED-to-camera communication channel. To overcome this problem, redundancy mechanisms are needed. In the following, we use the MMBP channel model to compare two simple, but widely used redundancy solutions : repeating a packet (RP) or repeating a sequence of packets (RS). We focus on the probability of delivering the entire quantity of information in a given number of transmissions, and we provide both analytical and experimental results, allowing us to validate the proposed MMBP model.

Fig. 3 shows, for the two mechanisms, the probability of integrally receiving N_p packets of data as a function of the number of retransmissions r. The results show quite a nice fit between the analytical and experimentation results, despite the assumptions required by our MMBP model.

In the left figure, we set $M = 5$ and $N = 2$; these values are in line with the packet length, the transmitter frequency and the camera capture interval experimentally observed for a distance of 5 cm between LED and camera. The results shows that, for the RS strategy, 3 retransmissions are needed to achieve a reception probability higher than 0.9, while this value raises to 6 for the RP strategy. On the right side of the figure, we show that the performance of the two strategies depends on the ratio between the number of S_{ON} and S_{OFF} states, $M : N$. When this ratio changes from 5 : 2 to 2 : 5, which practically corresponds to increasing the distance between the LED and the camera, RP gives better results than RS. Indeed, for the RS method, the success probability sharply decrease when $M < 3$ and stays below 0.6 even for 10 retransmission.

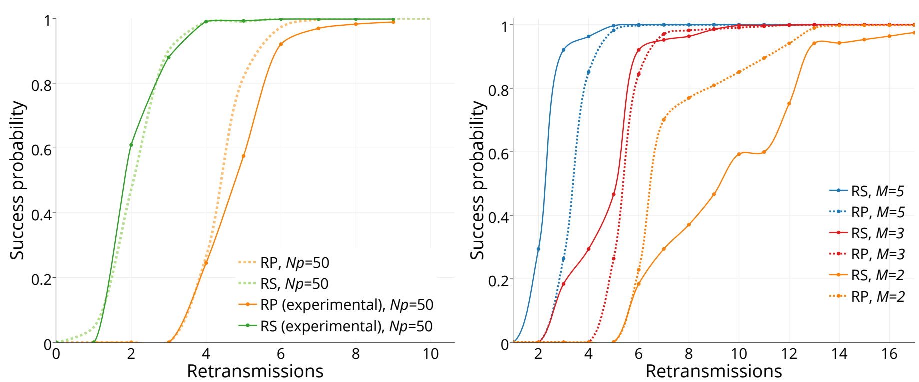

FIGURE 3: Comparison between RS and RP. On the left, analytical and experimental results for $M = 5$ and $N = 2$. On the right, analytical results when $M + N = 7$, but the $M : N$ ratio changes. In both cases, $N_p = 50$.

Practically, this means that RP is more suitable when the distance between the LED and the camera is higher, while RS is better for short communication distances. This phenomenon was previously unknown in the research community, but it is straightforward to study with our analytical model.

3 The CamComSim Simulator

We use the MMBP model described above, as well as photogrammetry rules required to compute the size of the ROI in the picture, to build *CamComSim*, an event-driven LED-to-camera simulator developed in Java and available as an open-source software under Apache license at `http://vlc.project.citi-lab.fr/camcomsim`.

To assess the correctness of our simulator, we compare its results with those obtained through a series of experiments on a LED-to-camera testbed. In the testbed experiments, we set the emitter symbol rate to 8 kHz and place it in standard indoor illumination conditions, near a window and illuminated with neon lights. The illuminance has been measured with a luxmeter at around 650 lux.

In Fig. 4, we present a comparison between simulation and experimental results, while playing on two key parameters of the system : the distance between the transmitter and the receiver, and the number of bytes to be transmitted. In all our experiments, the simulation and experimental results are very similar, validating our approach.

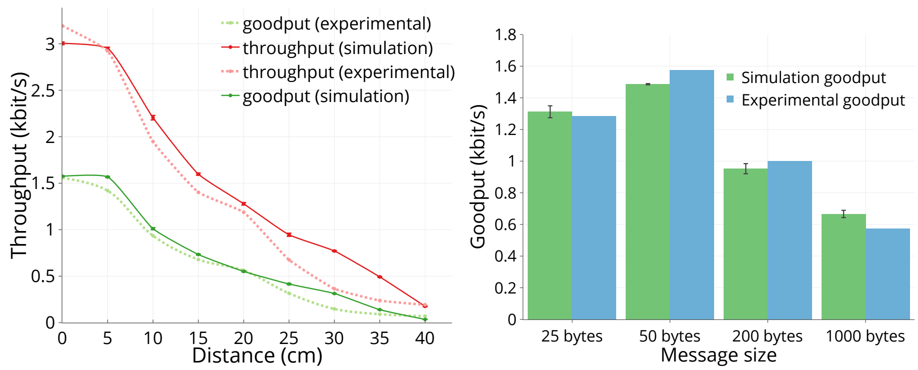

FIGURE 4: Comparison of simulation and experimental results depending on the distance between LED and camera (left) and the size of the total information to be transmitted (right).

On the left side of Fig. 4, we show both the troughput and goodput obtained by our system. The impact of the lossy LED-to-camera channel and the numerous retransmissions used by the transmitter is clearly visible in the difference between the two metrics. Also, while the throughput remains constant regardless the amount of information to be transmitted, the goodput drops when the size of the message to be transmitted increases, as demonstrated by the results on the right side of the figure.

4 Conclusion

In this paper, we introduced *CamComSim*, the first simulator for the design, the prototyping and the development of protocols and applications for LED-to-camera communication. Our event driven simulator is based on an MMBP channel model, and it relies on a standalone Java application that is easily extensible through a set of interfaces. We have validated *CamComSim* comparing simulation results with the performance reached by a real life testbed. The results highlight that our simulator is very precise and can predict the performance of a LED-to-camera system with less than 10% of error in most cases. The availability of accurate performance evaluation tools offers a great ease of use and the opportunity to tune protocols without the burden of always realizing experiments on a testbed.

Références

[1] C. Danakis, M. Afgani, G. Povey, I. Underwood, H. Haas. “Using a CMOS Camera Sensor for Visible Light Communication”. *Proc. IEEE OWC 2012*, Anaheim, CA, USA, Dec. 2012.

[2] T. Nguyen, Y.M. Jang. “High-speed Asynchronous Optical Camera Communication using LED and Rolling Shutter Camera”. *Proc. ICUFN 2015*, Sapporo, Japan, Jul. 2015.

[3] H.-Y. Lee, H.-M. Lin, Y.-L. Wei, H.-I. Wu, H.-M. Tsai, C.-J. Lin. “RollingLight : Enabling Line-of-Sight Light-to-Camera Communications”. *Proc. ACM MobiSys 2015*, New York, NY, USA, May 2015.

[4] H. Du, J. Han, X. Jian, T. Jung, C. Bo, Y. Wang, X.-Y. Li. “Martian : Message Broadcast via LED Lights to Heterogeneous Smartphones”. *IEEE Journal on Selected Areas in Communications*, vol. 35, no. 5, pp. 1154-1162, May 2017.

[5] S. Zhu, X. Zhang. “Enabling High-Precision Visible Light Localization in Today’s Buildings”. *Proc. ACM MobiSys 2017*, Niagara Falls, NY, USA, Jun. 2017.

[6] T. Li, C. An, Z. Tian, A.T. Campbell, X. Zhou. “Human Sensing Using Visible Light Communication”. *Proc. ACM MobiCom 2015*, Paris, France, Sep. 2015.

[7] S. Zhu, C. Zhang, X. Zhang. “Automating Visual Privacy Protection Using a Smart LED”. *Proc. ACM MobiCom 2017*, Snowbird, UT, USA, Oct. 2017.